TECHNICAL REPORT
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DEVELOPMENT OF COMBAT UNIFORM FABRICS EXHIBITING DURABLE ELECTROSTATIC DISSIPATION PROPERTIES

by
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Final Report
October 1990 - February 1992

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Soldier Systems Center
Natick, Massachusetts 01760-5019

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14. ABSTRACT
DuPont developed a new electrostatic dissipative fiber called P140. Seven yards of fabric, containing warp and filling bands of various blends of cotton, nylon, and P140, were manufactured to determine the appropriate fiber ratio to achieve the desired electrostatic dissipative performance. These fabrics were tested for electrostatic decay properties initially, after 5, 10, 20, and 30 wash cycles. Most all of the fabrics containing P140 fiber accepted at least the minimum required level of 4000 volts and demonstrated overall decay times of less than 0.5 seconds through 30 wash cycles. One percent P140 was selected as the optimum level for long term durability and protection and was further evaluated in the standard nylon/cotton twill configuration.
Three hundred yards of the Temperate Battledress Uniform (BDU) fabric were manufactured with 50 percent cotton, 49 percent nylon, and 1 percent P140. The addition of 1 percent P140 fiber to the nylon and cotton blend fabric resulted in durable electrostatic dissipation through 30 wash cycles and did not detrimentally affect physical, colorfastness, shade or infrared reflectance properties.

15. SUBJECT TERMS

COMBAT UNIFORMS	ELECTROSTATIC DISSIPATION	TEST AND EVALUATION
FABRICS	ELECTROSTATIC CHARGE	DECAY TIME
DURABILITY	ELECTROSTATIC RESISTIVITY	COLORFASTNESS
BATTLE DRESS UNIFORMS	PHYSICAL PROPERTIES	INFRARED REFLECTANCE

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PREFACE

The U.S. Army Quartermaster School expressed concern regarding accidental fuel ignition through the discharge of built-up electrostatic charge in clothing. The Natick Soldier Center established an effort to investigate the potential to integrate durable electrostatic dissipation protection in combat uniform fabrics. In a leveraged effort with DuPont, Natick developed, tested, and evaluated several nylon/cotton blend fabrics with various levels of a new static dissipative fiber called P140. The developmental fabrics were tested initially and after numerous launderings. A nylon/cotton/P140 blend ratio was established that provides durable electrostatic dissipation through 30 launderings, and does not detrimentally affect any other fabric performance property.

This project was undertaken during the period October 1990 to February 1992, and funded under the Program Element Number 622786 and Project Number AH98.

DEVELOPMENT OF COMBAT UNIFORM FABRICS EXHIBIITING DURABLE ELECTROSTATIC DISSIPATION PROPERTIES

SUMMARY

Build up of electrostatic charge on a uniform can pose an extreme hazard to fuel handlers and other electrostatic-sensitive occupations. For example, the Quartermaster School has expressed concern regarding accidental fuel ignition through the discharge of built-up electrostatic charge in clothing. The technology to provide durable electrostatic-resistant battle dress uniform fabric has not been available until recently. The purpose of this effort was to evaluate the physical properties of various fabrics containing DuPont's P140 electrostatic dissipative fiber. Development efforts focused on protective and integrated combat clothing applications in support of O&MA program: Improved Battledress Uniform (BDU) Fabric and AH98 AA 6.2 program: Materials with Integrated Protection.

DuPont recently developed a new static dissipative fiber called P140. It has a sheath core construction with a circular core of black conductive carbon and a protective nylon sheath. Static dissipation is achieved through an induction mechanism rather than by conduction.[1] Seven yards of fabric containing warp and filling bands of various blends of cotton, nylon, and P140 were manufactured to evaluate inclusion of the static dissipative fiber, and determine the appropriate fiber ratio to achieve the desired electrostatic dissipative properties.

All of these fabrics were tested for electrostatic decay properties initially and following 5, 10, 20, and 30 wash cycles. The majority of the fabrics containing P140 fiber accepted at least the minimum required level of 4000 volts and demonstrated overall decay times of less than 0.5 seconds through 30 wash cycles. The sample containing the most P140 (2.5 percent) maintained both consistent and low decay times through 30 wash cycles in both the warp and filling directions. The control fabric, containing no P140 fiber, accepted the required minimum of 4,000 volts initially but the decay time was 9.5 seconds, exceeding the maximum decay time of less than 0.5 seconds.

One percent P140 was selected as the optimum level for long-term durability and protection and was further evaluated in the standard nylon/cotton twill configuration. Three hundred yards of the Temperate BDU fabric (VEE 6633) was manufactured with 50 percent cotton, 49 percent nylon, and 1 percent P140. Physical properties, shade, colorfastness, and infrared reflectance were evaluated in accordance with MIL-C-44031.

The addition of 1 percent P140 fiber to the nylon and cotton blend fabric demonstrated durable electrostatic dissipation through 30 wash cycles and did not detrimentally affect physical, colorfastness, shade or infrared reflectance properties when incorporated in the Temperate BDU configuration. The VEE 6633 met all of the physical property requirements and demonstrated comparable data to VEE 6345, the standard (MIL-C-44031) Temperate BDU fabric purchased from Defense Supply Center Philadelphia (DSCP) stock. The fabric met all requirements for infrared reflectance and matched the shade of the standard roll. The fabric met all requirements for colorfastness,

with the exception of colorfastness to wet crocking for dark green with a rating of 2.5 versus the minimum rating of 3.5. This is considered to be a minimal failure and judged correctable. As expected, the fabric met the test method requirements for electrostatic decay both initially and after five cycles.

In addition, P140 was investigated in staple Kevlar® blend fabrics as part of the Materials with Integrated Protection program. Only 1 percent was incorporated in a blend of 72.5 percent Pima cotton and 26.5 percent Kevlar (VEE 6620). While the fabric met the required overall decay time requirement, it did not accept the minimum required voltage. This data and the nylon/cotton/P140 data previously discussed suggest that increasing the amount of P140 to 2 percent would most likely meet the minimum required voltage.

INTRODUCTION

Currently, military specifications for Fuel Handler's clothing do not contain requirements for electrostatic decay. Fuel Handlers generally wear standard issue clothing such as the BDU and Field Coat. The Quartermaster School has expressed concern regarding accidental fuel ignition through the discharge of built up electrostatic charge in clothing. However, the technology to provide durable electrostatic resistant battledress uniform fabric has not been available until recently. A uniform fabric with integrated protection against both electrostatic and flame, as well as chemical/biological and surveillance threats, is ultimately desired as identified in several of Natick's Science and Technology Objectives. However, this report will focus on the feasibility of providing durable electrostatic resistance in both existing combat uniform fabrics and next generation fabrics with integrated protection.

FABRIC DESCRIPTION

The seven fabrics evaluated in this effort are identified as follows:

1. VEE 6468/1 – 7.8 ounces per square yard, plain weave, 50 percent cotton, 47.5 percent Type 420 nylon, 2.5 percent P140, desized and scoured.
2. VEE 6468/2 – 7.9 ounces per square yard, plain weave, 50 percent cotton, 48.8 percent Type 420 nylon, 1.2 percent P140, desized and scoured.
3. VEE 6468/3 – 8.0 ounces per square yard, plain weave, 50 percent cotton, 49.4 percent Type 420 nylon, 0.6 percent P140, desized and scoured.
4. VEE 6468/4 – 8.1 ounces per square yard, plain weave, 50 percent cotton, 50 percent Type 420 nylon, desized and scoured, used as a control.
5. VEE 6633 – 7.4 ounces per square yard, left hand twill, 50 percent cotton, 49 percent Type 420 nylon, 1.0 percent P140, Woodland Camouflage Printed manufactured in accordance with MIL-C-44031, Cloth, Camouflage Pattern, Woodland, Cotton and Nylon.
6. VEE 6345 – 7.3 ounces per square yard, left hand twill, 50 percent cotton, 50 percent Type 420 nylon, Woodland Camouflage Printed manufactured in accordance with MIL-C-44031, purchased from DSCP procured stock and used in this study as a control.
7. VEE 6620 – 6.3 ounces per square yard, left hand twill, 72.5 percent Pima cotton, 26.5 percent Kevlar, 1.0 percent P140, flame-resistant treated, Woodland Camouflage Printed.

TEST METHODOLOGY

All tests were performed in accordance with either American Society for Testing and Materials (ASTM) or American Association of Textile Chemists and Colorists (AATCC) test methods as listed in the Appendix. Federal Test Method 5931, Determination of Electrostatic Decay of Fabrics, identifies the time it takes for a charge on a fabric surface to decay to an electrostatically safe level. According to this method, an electrostatically safe level is defined as when a fabric is charged toward 5000 volts, and reaches a minimum level of 4000 volts, dissipation of 90 percent of this charge occurs within 0.5 second. The sample fabrics were tested at 20 percent relative humidity and 75 degrees Fahrenheit.

RESULTS AND DISCUSSIONS

DuPont's P140 has a sheath core construction with a circular core of black conductive carbon and a protective nylon sheath. Static dissipation is achieved by induction rather than conduction.[1] P140 has a tenacity of 2.5 grams/denier before it is crimped.[2] DuPont also markets a static dissipative fiber called Negastat®, which differs from P140 in that it has a trilobal core and is more expensive than P140. Because of the increased cost, Negastat was not tested in this evaluation.

All of the evaluated fabrics containing P140 were developed and supplied by DuPont based on Natick recommendations, and support Natick's leveraging efforts with

industry. The P140 fiber used in the sample fabrics was specially drawn down from 9 denier per filament (dpf) to 3 dpf, which is more compatible with cotton (1.2 dpf) and nylon (2.5 dpf). The drawdown also enhances fiber blending and prevents fiber migration. The Surgeon General has approved P140 for use in military clothing.

Seven yards of fabric containing warp and filling bands of various blends of cotton, nylon, and P140 were manufactured to determine the appropriate fiber ratio to achieve the desired properties. The four resulting fabrics are identified as VEE 6468/1-4. VEE 6468/1-3 contains 2.5, 1.2, and 0.6 percent P140, respectively. VEE 6468/4 contains no P140 and is considered to be the control sample for the VEE 6468 series. These fabrics were tested for electrostatic decay properties initially, and after 5, 10, 20, and 30 wash cycles, the results are listed in Tables 1 and 2.

Most all of the fabrics containing P140 fiber accepted at least the minimum required level of 4000 volts and demonstrated overall decay times of less than 0.5 seconds through 30 wash cycles. The sample containing 0.6 percent P140, which was the smallest amount, failed to meet the minimum level of 4,000 volts after 30 wash cycles, but still dissipated the charge in less than 0.5 seconds.

TABLE 1. Decay Time of Cotton/Nylon/P140 Blend Fabrics, Warp x Filling, Seconds[1]

Number of Wash Cycles (AATCC-96)	**50% Cotton 47.5% Nylon 2.5% P140 VEE 6468/1**	**50% Cotton 48.8% Nylon 1.2% P140 VEE 6468/2**	**50% Cotton 49.4% Nylon 0.6% P140 VEE 6468/3**	**50% Cotton 50% Nylon VEE 6468/4**
Initial	0.01 x 0.01	0.03 x 0.05	0.21 x 0.22	7.66
5	0.01 x 0.01	0.02 x0.01	0.05 x 0.05	36.63 x 43.95
10	0.01 x 0.01	0.01 x 0.01	0.01 x 0.01	[2]
20	0.01 x 0.01	0.01 x 0.01	0.04 x 0.02	[2]
30	0.01 x 0.01	0.03 x 0.06	0.08 x 0.38	[2]

[1] Required decay time is less than 0.5 seconds.

[2] This sample was not tested due to high residual charge level, which may damage test equipment.

TABLE 2. V_{max} of Cotton/Nylon/P140 Blend Fabrics, Warp x Filling, Volts[1]

Number of Wash Cycles (AATCC-96)	50% Cotton 47.5% Nylon 2.5% P140 VEE 6468/1	50% Cotton 48.8% Nylon 1.2% P140 VEE 6468/2	50% Cotton 49.4% Nylon 0.6% P140 VEE 6468/3	50% Cotton 50% Nylon VEE 6468/4
Initial	5000 x 4896	4875 x 4875	4813 x 4688	4896 x 4833
5	4646 x 4583	4604 x 4500	4396 x 4396	3271 x 2563
10	4396 x 4417	4229 x 4229	4021 x 4125	[2]
20	4354 x 4375	4333 x 4250	4125 x 4000	[2]
30	4771 x 4667	4396 x 4375	4146 x 3938[3]	[2]

[1] When charged toward 5000 volts, the cloth is required to reach a minimum level of 4000 volts.
[2] This sample was not tested due to high residual charge level, which may damage test equipment.
[3] This fabric did not meet the required minimum level of 4000 volts.

As demonstrated in Figures 1 and 2, the samples containing the most P140 (2.5 percent) maintained consistent, low decay times through 30 wash cycles in both the warp and filling directions. The samples containing 1.2 and 0.6 percent P140 demonstrated higher decay times initially and after 30 wash cycles. Generally, high initial decay times can be attributed to unknown finishes or contaminants; however, all of the fabrics were desized and scoured at the same time and were not finished with a surface treatment.

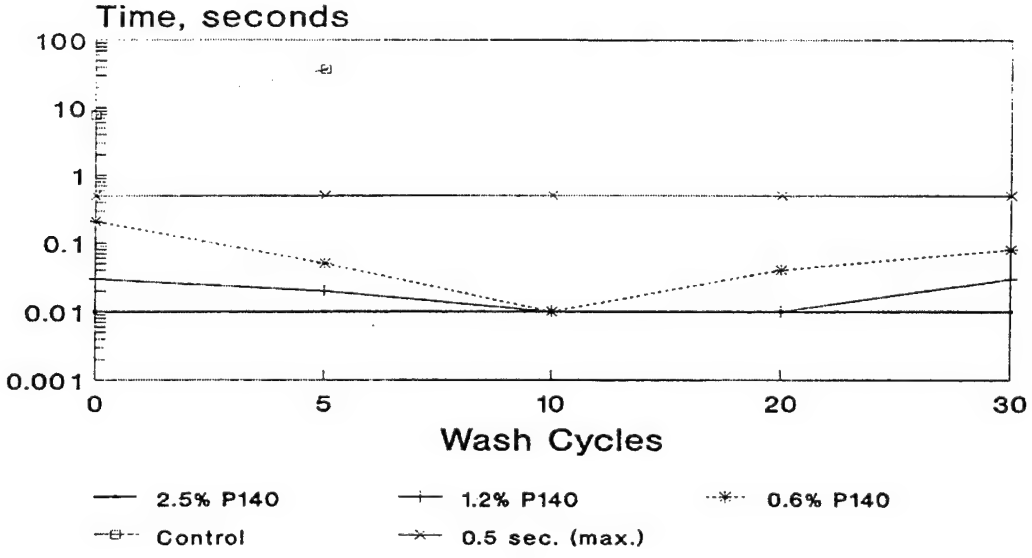

Figure 1. Decay Time of Cotton/Nylon/P140 Blend Fabric, Warp Direction.

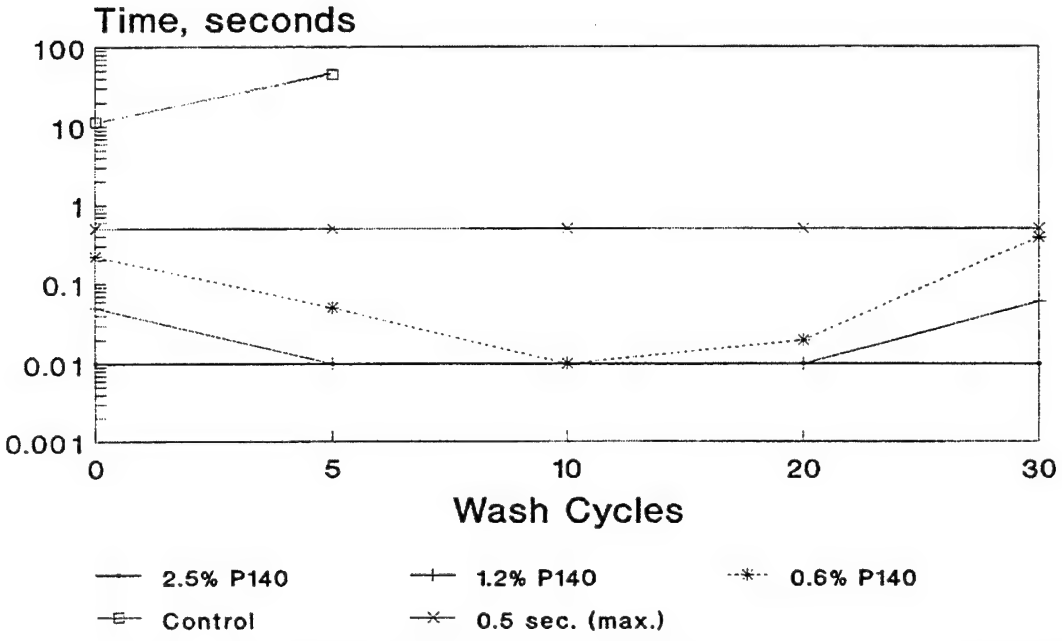

Figure 2. Decay Time of Cotton/Nylon/P140 Blend Fabric, Filling Direction

Figures 3 and 4 demonstrate that the sample containing 2.5 percent P140 reached consistently higher voltage levels than the samples containing 1.2 and 0.6 percent P140, through 30 wash cycles in both the warp and filling directions.

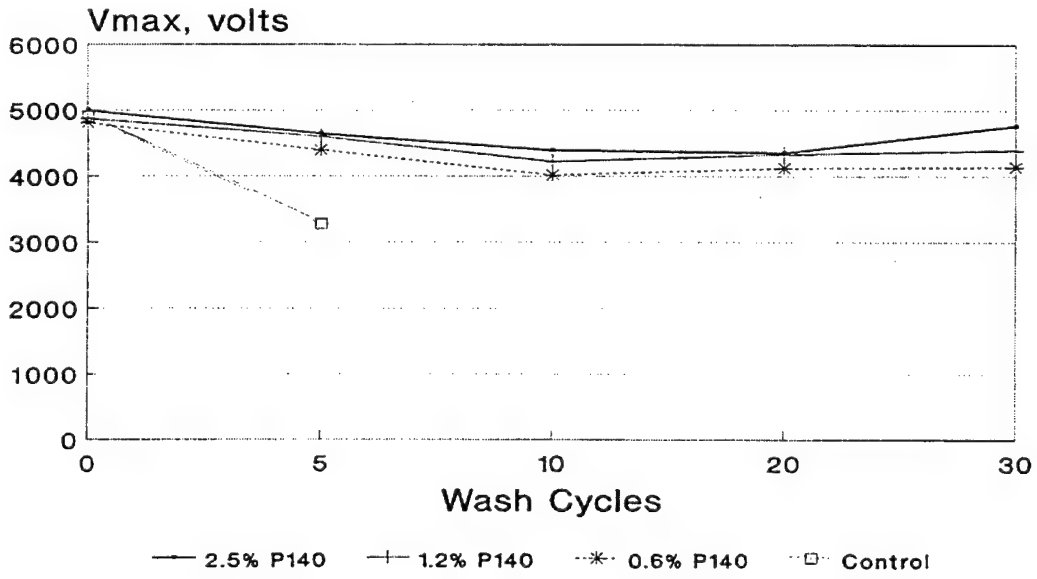

Figure 3. Vmax of Cotton/Nylon/P140 Blend Fabric, Warp Direction

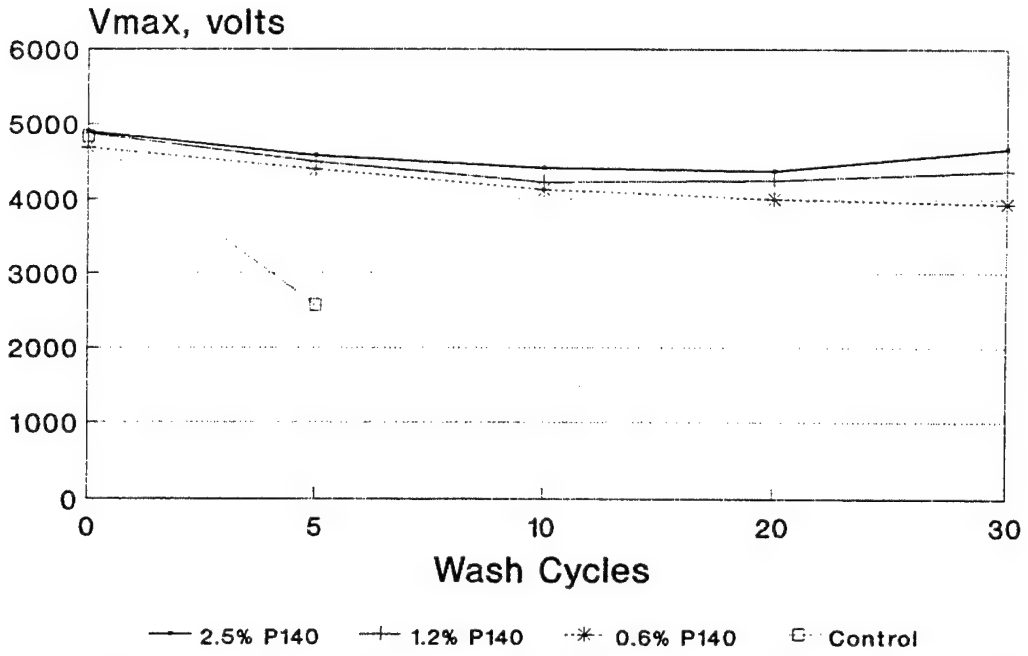

Figure 4. Vmax of Cotton/Nylon/P140 Blend Fabric, Filling Direction

The control fabric (VEE 6468/4), containing no P140 fiber, accepted the required minimum of 4,000 volts initially but the decay time was 9.5 seconds, exceeding the maximum decay time of less than 0.5 seconds. After five wash cycles it did not accept the minimum voltage and the decay time was 40.3 seconds. In addition, the control was no longer tested because the high residual charge may damage the test equipment.

Based on the consistent, low decay values, and high voltage levels demonstrated in Figures 1-4, one percent P140 was selected as the optimum level for long term durability and protection and was further evaluated in the standard nylon/cotton twill configuration.

Three hundred yards of the Temperate BDU fabric was manufactured with 50 percent cotton, 49 percent nylon, and 1 percent P140 by Delta Mills. Delta Mills is one of DSCP's largest suppliers of Temperate and Desert BDU shell fabrics. The fabric is identified as VEE 6633. Physical properties, shade, colorfastness, and infrared reflectance were evaluated according to MIL-C-44031 requirements and the results are listed in Tables 3-5.

TABLE 3. Physical and Electrostatic Properties of Cotton/Nylon/P140 Blend and TBDU Fabrics

Properties	VEE 6633	Standard TBDU VEE 6345	MIL-C-44031 Requirements
Weight, oz/yd^2	7.4	7.3	6.8 (min.)
Yarns per Inch Warp x Filling	87 x 56	86 x 57	86 x 54 (min.)
Breaking Strength, lbs Warp x Filling	276 x 212	239 x 167	200 x 125 (min.)
Elongation, % Warp x Filling	37 x 33	-	-
Tearing Strength, lbs Warp x Filling	14 x 13	16 x 13	11 x 8 (min.)
Air Permeability $ft^3/min/ft^2$	4.4	16.8	25.0 (max.)
Electrostatic Decay, sec			
Initial	0.02 x 0.06	-	-
After 5 Wash Cycles	0.01 x 0.01	-	-
After 30 Wash Cycles	0.21 x 0.36	-	-
Vmax, volts			
Initial	4863 x 4813	-	-
5 Wash Cycles	4333 x 4228	-	-
30 Wash Cycles	4375 x 4385	-	-

TABLE 4. Colorfastness and Shade of Cotton/Nylon/P140 Blend Fabric (VEE 6633)

	COLOR			
	Light Green	**Dark Green**	**Brown**	**Black**
Colorfastness to:[1] Light, 40 SFH	Good	Excellent	Excellent	Excellent
Crocking, Dry	4.5	4.5	4.5	4.5
Wet	4.0	2.5 [2]	2.5	2.5
Perspiration, Alk/Acid[3]	Excellent	Excellent	Excellent	Excellent
Laundering, 3 Cycles[4]	Good	Good	Good	Good
Shade[5]	Pass	Pass	Pass	Pass

[1] Evaluated against standard roll 3286.
[2] Failure: Standard rating for Dark Green is 3.5.
[3] All samples and 6 fiber swatch - excellent, except Light and Dark Green nylon fiber for alkaline test, which is good.
[4] All samples - good, cotton - excellent, nylon - fair.
[5] Evaluated against standard roll 3055

TABLE 5.

Near Infrared Reflectance of Cotton/Nylon/P140 Blend Fabric

Wavelength (NM)	MIL-C-44031 Lt. Green Requirement Max.	MIL-C-44031 Lt. Green Requirement Min.	Lt. Green 354 VEE 6633	MIL-C-44031 Dk. Green & Brown Requirement Max.	MIL-C-44031 Dk. Green & Brown Requirement Min.	Dk. Green 355 VEE 6633	Brown 356 VEE 6633	MIL-C-44031 Black Req. Max.	Black 357 VEE 6633
600	18	8	13	10	3	7	6	10	3
620	18	8	13	10	3	6	6	10	3
640	18	8	13	9	3	6	6	10	3
660	18	8	13	12	3	6	7	10	3
680	22	10	16	14	3	7	8	10	4
700	33	18	20	18	5	8	10	10	5
720	45	22	25	20	7	11	13	10	5
740	55	30	32	28	12	15	18	10	6
760	65	35	40	36	18	21	24	10	6
780	75	40	48	44	26	29	32	10	6
800	80	45	55	52	34	37	40	10	6
820	86	50	61	60	42	45	47	10	6
840	88	55	65	68	50	53	54	10	7
860	90	60	68	74	56	59	59	10	7

The VEE 6633 met all of the physical property requirements and demonstrated comparable data to VEE 6345, which is standard Temperate BDU fabric purchased from DSCP stock. The fabric met all requirements for infrared reflectance and matched the shade of the standard roll. The fabric met all requirements for colorfastness, with the exception of colorfastness to wet crocking for dark green with a rating of 2.5 versus the minimum rating of 3.5. This is considered to be a minimal failure and judged correctable. As expected, the fabric met the test method requirements for electrostatic decay both initially and after five cycles.

The P140 has also been investigated in staple Kevlar blend fabrics as part of the Materials with Integrated Protection program. Only 1 percent was incorporated in a blend of 72.5 percent Pima cotton and 26.5 percent Kevlar (VEE 6620). The physical and electrostatic properties are listed in Table 6. While the fabric met the overall decay time requirement, it did not accept the minimum required voltage. This data and the nylon/cotton/P140 fabric data previously discussed suggest that increasing the amount of P140 to 2 percent would most likely meet the minimum required voltage.

TABLE 6. Physical and Electrostatic Properties of Cotton/Kevlar/P140 Blend Fabrics (VEE 6620)

Properties	**VEE 6620**
Weight, oz/yd.^{2}	6.3
Yarns per Inch Warp x Filling	101 x 90
Breaking Strength, lbs. Warp x Filling	182 x 178
Elongation, % Warp x Filling	6 x 10
Tearing Strength, lbs. Warp x Filling After 5 Launderings	4.2 x 6.2
Air Permeability ft.^{3}/min./ft.^{2}	13.3
Electrostatic Decay, sec. Initial After 5 Wash Cycles	0.01 x 0.01 0.01 x 0.01
V_{max}, volts Initial After 5 Wash Cycles	3958 x 3875 3938 x 3844

CONCLUSIONS

The addition of 1 percent P140 fiber to nylon and cotton blend fabric demonstrates durable electrostatic dissipation through 30 wash cycles and does not detrimentally affect

physical, colorfastness, shade or infrared reflectance properties when incorporated in the Temperate BDU configuration.

RECOMMENDATIONS

1. Consider adoption of 1 percent P140 in the Temperate BDU fabric to provide durable electrostatic decay properties for fuel handlers and other electrostatic sensitive occupations. DuPont's estimated added cost of the P140 fiber is 5-7 cents per yard of finished fabric.
2. Evaluate Nomex® and P140 blends for use in the Air Crew BDU and tanker's coverall. This recommendation was previously made to DuPont in a letter dated 6 May 1991.
3. Continue development efforts regarding flame resistant treated cotton/Kevlar/nylon and P140 blends in support of the Materials with Integrated Protection program.

This document reports research undertaken at the U.S. Army Soldier and Biological Chemical Command, Soldier Systems Center, Natick, MA, and has been assigned No. NATICK/TR-02/009 in a series of reports approved for publication.

REFERENCES

1. "An Aramid Fiber Blend for Protection Against Flash Fires", High Performance Textiles, p. 3, July 1991
2. Electronic Mail, from O. David Martin, DuPont, to Carole Winterhalter, U.S. Army Soldier and Biological Chemical Command, March 8, 2002.

APPENDIX

Test Methods

AATCC	Title
AATCC-8	Colorfastness to Crocking: AATCC Crockmeter Method
AATCC-15	Colorfastness to Perspiration
AATCC-16 Opt. A	Colorfastness to Light
AATCC-61 Test 3A	Colorfastness to Laundering, Home and Commercial: Accelerated
AATCC-96 Test VI, A	Dimensional Changes in Commercial Laundering of Woven and Knitted Fabrics Except Wool

ASTM	Title
ASTM D 737	Air Permeability of Textile Fabrics
ASTM D 1424	Tear Resistance of Woven Fabric by Falling Pendulum (Elmendorf) Apparatus
ASTM D 3775	Fabric Count of Woven Fabrics
ASTM D 3776	Mass Per Unit Area (Weight) of Fabric Option C
ASTM D 5034	Standard Test Method for Breaking Strength and Elongation: Grab Test

FEDERAL	Title
5931	Determination of Electrostatic Decay of Fabrics